# 11.—Foraminifera of Hardy Inlet, southwestern Australia

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## Abstract

Total foraminiferal faunas were examined from 18 samples from Hardy Inlet and a nearby beach as part of a much broader study of the Blackwood River estuary under the auspices of the Department of Conservation and Environment.

Several regimes can be identified on the basis of foraminifera and these correspond closely with geomorphic and hydrological regimes.

Faunas in the upstream part of the tidal river regime are dominated by *Ammonia beccarii* although diversity and foraminiferal number are low.

The delta faunas and those from the tidal river near the delta are dominated by agglutinated forms, although again, diversity and foraminiferal number generally are low.

Lagoon faunas are dominated by species of *Ammobaculites* and diversity and foraminiferal number, while still low, are higher than in samples from farther upstream.

River mouth, beach and Deadwater faunas are abundant and very diverse with typical shallow marine faunas dominated by *Elphidium-Discorbis-Cibicides*.

Swan Lakes fauna is dominated by ostracods. The foraminiferal fauna is dominantly *Ammonia-Elphidium*.


## Introduction

Foraminifera consitute a group of skeleton-producing protozoans with a long geological history. Several important summaries of the biology and classification of this important group have been prepared, the most significant being those by Cushman (1948), Glaessner (1945) and especially Loeblich and Tappan (1964). The distribution of recent foraminifera has been the subject of several reviews in recent years and important contributions have been made by Phleger (1960) and most recently by Murray (1973).

For many years, the study of the distribution of living foraminifera has been related to the needs of oil exploration companies for reconstruction of past environments. To this end, foraminifera of the Gulf of Mexico and nearby areas have been studied in great detail (see Walton 1964; Seiglie 1970 *et seq.*, Phleger 1951, 1955 etc.).

More recently there has been a tendency to study distributions of these organisms in man-made or man-affected situations (e.g. Bandy, Ingle and Resig 1964, *et seq.*) although the use of foraminifera for documenting changes due to pollution is in its infancy (Schafer 1970). The Hardy Inlet is a relatively small area and could prove an ideal test case for changes due to mining if mining is undertaken in the area.

In Australia, little has been published on distribution of foraminifera from the major river systems but Albani (1968, *et seq.*) and colleagues have made significant studies in New South Wales. Apthorpe (1974) has recently studied foraminifera from the Gippsland lakes of Victoria. McKenzie (1962) has made the only study in a comparable area from Western Australia. Work is proceeding on a similar study of Swan River foraminifera.

## Methods

This report is based on an examination of 17 box core samples from within the Hardy Inlet and Swan Lakes and Deadwater. In addition, a single beach sand sample was taken immediately south of Deadwater to compare the oceanic and saline lake faunas. Rose Bengal staining of samples was attempted but the attempt can only be regarded as a failure. The results are based on total faunas only.

Most samples were taken on 29 June 1974 when the Hardy Inlet proper was approximately at a winter condition. Later sampling at Station 9 (See Figure 1) was done to detect any difference between winter and summer distribution patterns. Localities and locality parameters are shown on Figure 1 and on the distribution charts. Also shown on Figure 1 are the sample localities which form part of a broader Hardy Inlet study (See Imberger and Agnew, in press). It was hoped that these sample localities could be used for the study of foraminifera but not all foraminiferal study sample stations are coincident with the standard localities.

The results given here are by no means the final study that could be made of the Hardy Inlet foraminifera but give only a preliminary estimate of their distribution. Longer term studies at many more stations are needed.

Samples represent the surface 1 cm from the top of each box core sample which was bottled, washed over a 100 $\mu$m sieve, and examined.

## Physical conditions in Hardy Inlet

### *Physiographic units of the Hardy Inlet*

Hodgkin has identified a series of physiographic units which are detailed by Imberger and Agnew (1974). They are as follows: tidal river, lagoon, channel, Deadwater and Swan Lakes, and mouth and sea bar. Throughout this report, these units will be used and are shown on Figure 3A.

The lagoon of Hodgkin can be divided conveniently into two regions for this work. The dominant one is the true delta of the Blackwood-

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Scott system which has a classic delta shape with well marked distributary channel pattern. One of these distributaries has been accentuated by dredging. The remainder of what was defined originally as lagoon will be referred to as lagoon proper.

To the units documented by Imberger and Agnew (1974) must be added oceanic beach, which is here represented by a single sample (18).

*Reliability of salinities, bathymetry etc.*

Detailed measurements of *salinity* (Figure 2) for Hardy Inlet have been made so far at short intervals over only one year (Imberger and Agnew, in press) so it is not certain that the

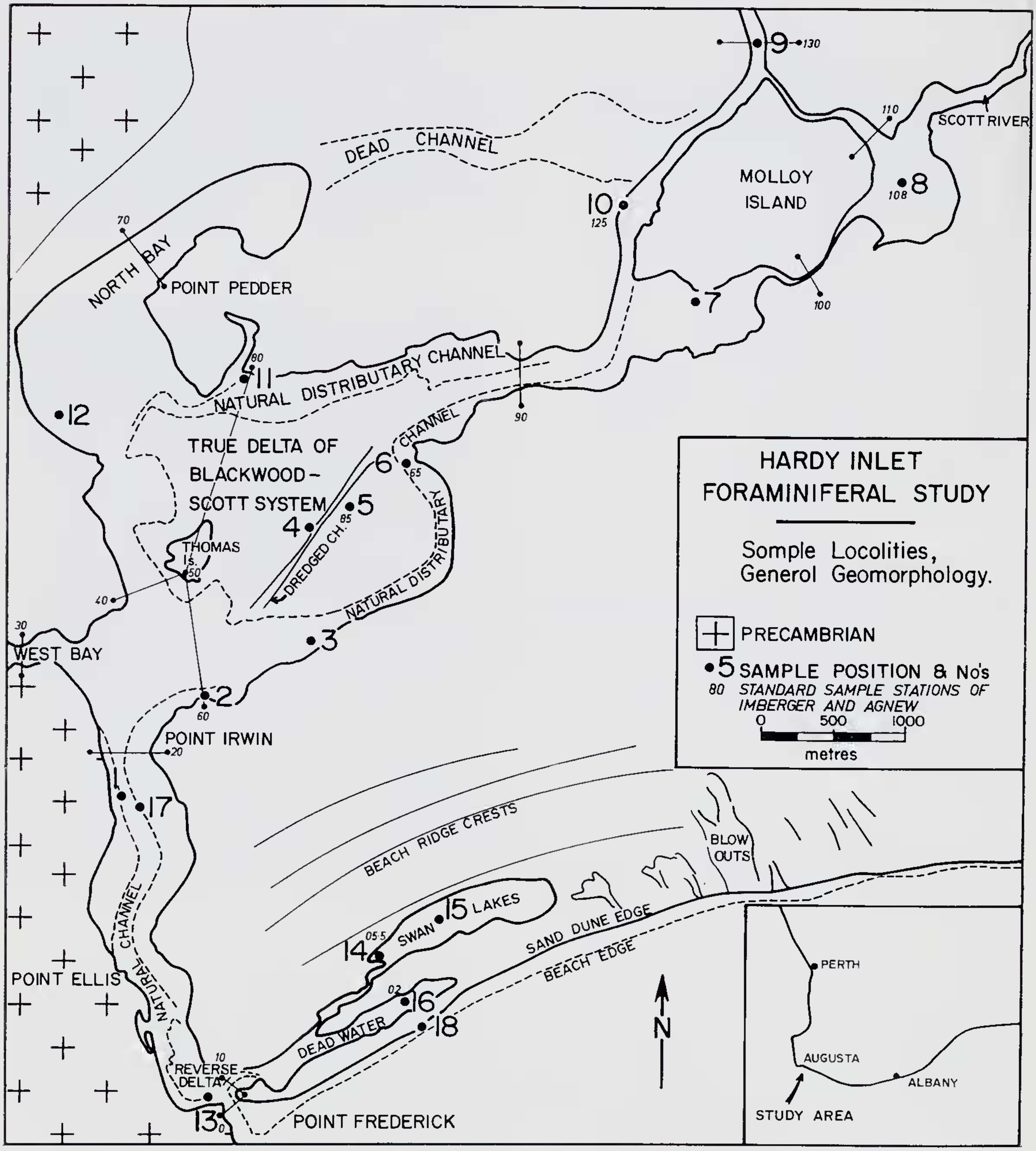


Figure 1.—Locality and geomorphology diagram.

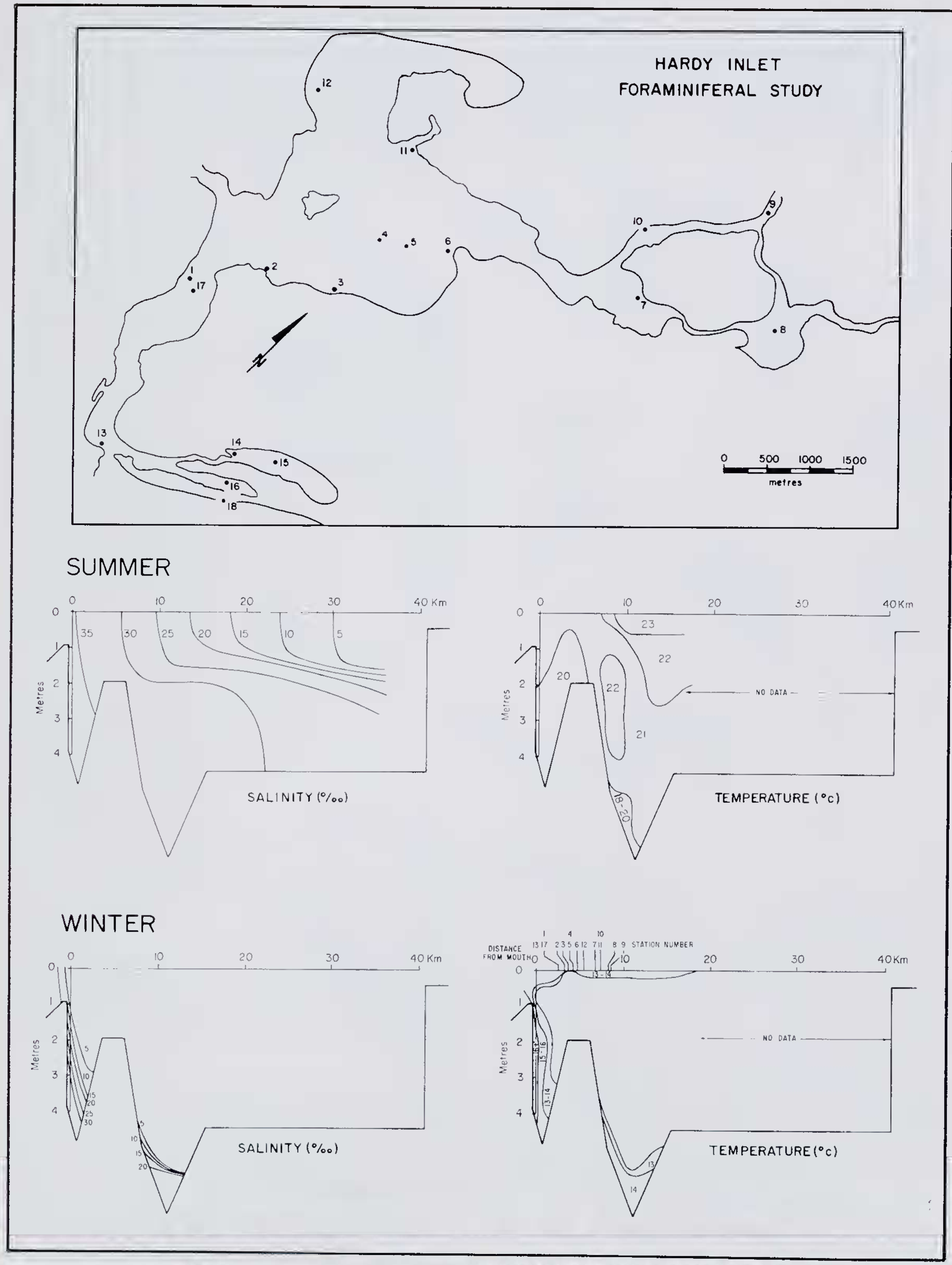


Figure 2.—Summer and winter salinity and temperature, Hardy Inlet.

figures given here are typical, although there is no reason to think that they are not. Virtually the entire system is at a salinity of less than 5 ‰ in typical winter pattern. The summer pattern is less uniform with surface salinity decreasing at approximately 1 ‰ per km upstream from the mouth.

It is noteworthy that the true delta of the Blackwood-Scott system acts as a shallow barrier between a deeper, more fluvial, channel upstream, and shallower lagoon proper and channel downstream. As a result of the barrier, a deeper level salt wedge may become stranded in the tidal channel upstream. This is discussed

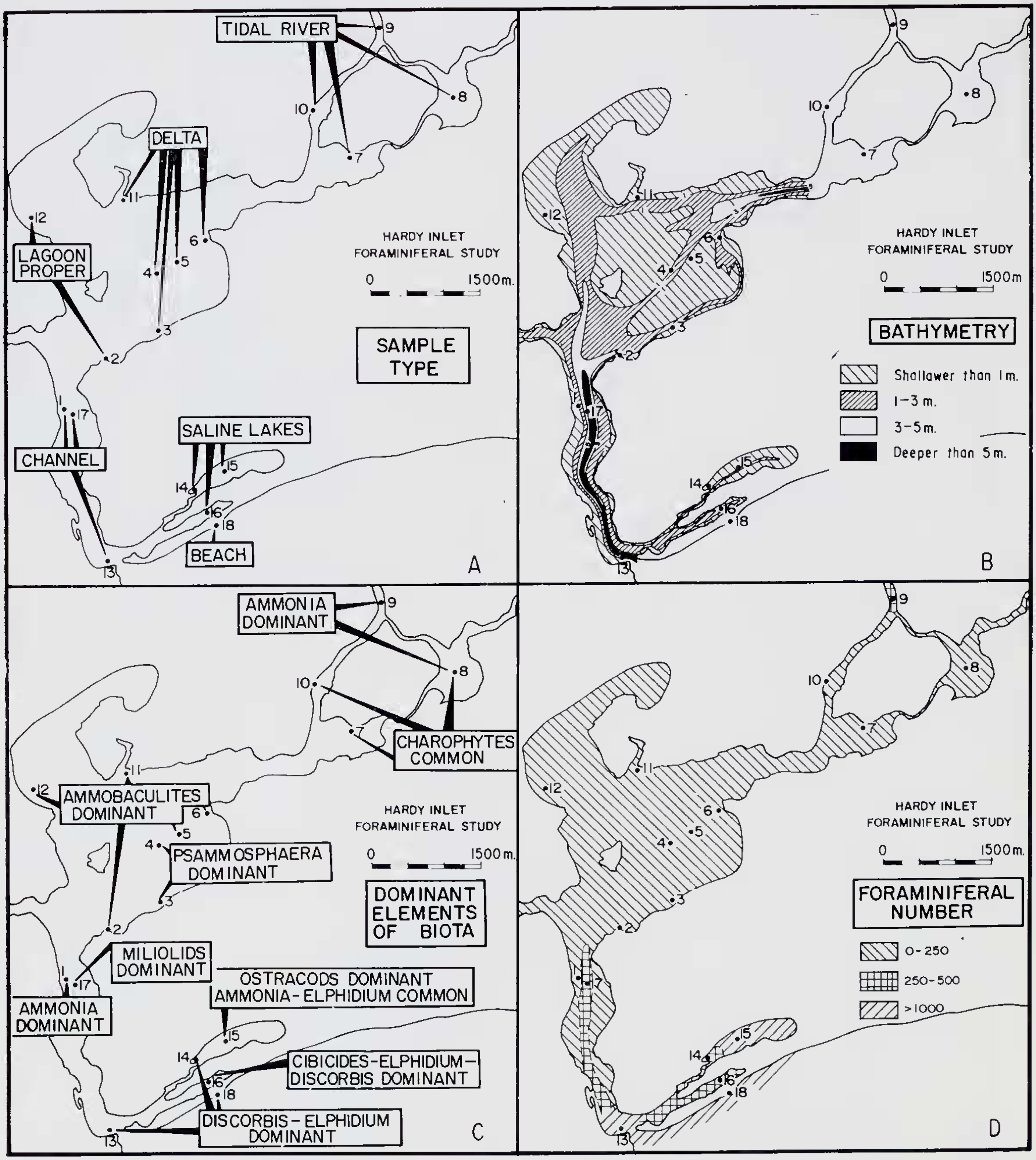


Figure 3.—Parameters of foraminiferal distribution; A. sample type; B. bathymetry; C. dominant elements of biota; D. foraminiferal number.

further by Imberger and Agnew (in press) and is shown in the salinity diagrams (Figure 2).

Final *bathymetry* maps are not available and Figure 3B is based on preliminary data taken by the Public Works Department.

*Water movement* is not yet well known but the information so far available is contained in Imberger and Agnew (in press). According to them, tidal variation has a maximum of about 1 m and is "normally not sufficient to break up any salt wedge system that may have formed".

In winter, water *temperatures* (Figure 2) in the river fall to about 12°C when the ocean outside the mouth is warmer, perhaps as low as 15°C. The contrast is between cooler, low salinity surface runoff and the warmer oceanic water. In summer the situation seems more complex. The ocean water, at 20°C, is cooler than the river water which is the converse of the winter condition.

Figure 2 purports to show the summer and winter salinity and temperature conditions. The bottom profile of the river is diagrammatic and is based on similar figures prepared by Imberger and Agnew (in press). 29 June 1974, the date of the first sampling, is taken as representing winter conditions although Imberger and Agnew (pers. comm.) suggest that in the full winter condition, no salt wedge is preserved north of the delta. 21 March 1974, is taken as typical of summer although there is the possibility that full summer maximum temperatures are a little above those shown on the figure.

### Sample details

The distribution of all species identified is shown on Figure 4 which also shows several other features of the samples studied. They are: *Distance* from the inlet mouth which in a general way corresponds with decrease in salinity. *Setting* which reiterates the classification shown on Figure 3A. *Water depth* at times of measurement. *Number of specimens* actually separated during the study. *Foraminiferal number* which is simply the number of specimens of foraminifera which can be expected from each gram of dry sediment. These figures are shown diagrammatically on Figure 3D. *Fisher α Index* which is an index of the diversity of the foraminiferal fauna (See Murray 1973). This figure must be regarded as very tentative because of the small specimen numbers studied. The number in each square is the number of specimens of the species recovered from the sample. Figure 3A shows the samples grouped according to environment.

#### *Tidal river samples*

The Tidal river regime is represented by four sample stations, 9 and 10 in the Blackwood River and 7 and 8 in the Scott River.

*Station 9* (Location 130 of Imberger and Agnew, in press). This is the farthest upstream sample examined and is the deepest sample taken.
*Sediment:* The sediment at this station consists of very fine grey mud, which when sieved is found to be composed almost completely of ovoid faecal pellets. The organisms responsible were not identified and the pellets are identical with those so abundant in the lagoon of the Swan River. Nowhere else in the Hardy Inlet are these so prominent.
*Salinity:* The winter salinity is less than 5 ‰ and in summer there is a weak halocline separating 20-25 ‰ above 2 m from 30 ‰ and over below. At the time of winter sampling (29 June, 1974), there was a very marked halocline at 5.5 m separating salinity of 2 ‰ above from 29 ‰ below.

*Station 10* (Location 125 of Imberger and Agnew).
*Sediment:* Fine angular quartz sand with minor mud.
*Salinity:* Similar to station 9 except that summer salinities may be marginally higher.

*Station 8* (Location 108 of Imberger and Agnew).
*Sediment:* Fine dark mud with angular sand.
*Salinity:* Winter salinities are less than 5 ‰. Summer values are about 30-35 ‰.

*Station 7*
*Sediment:* Fine angular quartz sand with dark, fine mud admixed. The calcareous foraminifer *Ammonia beccarii* shows some dissolution effects (see plates) which indicate a pH significantly below 7 for some time of the year at least.
*Salinity:* Values would not differ significantly from those at Station 8.

#### *Lagoon samples*

A.—Blackwood-Scott Delta

*Station 6* (Location 65 of Imberger and Agnew).
*Sediment:* Poorly sorted angular fine quartz sand and considerable black mud.
*Salinity:* Winter—less than 5 ‰. Summer—30-35 ‰.

*Station 5* (Location 85 of Imberger and Agnew).
*Sediment:* Fine quartz sand with some heavy mineral and minor mud.
*Salinity:* Winter—less than 5 ‰. Summer—30-35 ‰.

*Station 4* Interdistributary sand.
*Sediment:* Muddy angular and rounded fine quartz sand.
*Salinity:* Winter—less than 5 ‰. Summer—30-35 ‰.

*Station 3* Mouth of interdistributary channel.
*Sediment:* Muddy angular quartz sand with minor heavy mineral.
*Salinity:* Winter—less than 5 ‰. Summer—30-35 ‰.

*Station 11* (Near Location 80 of Imberger and Agnew)—broad distributary channel.
*Sediment:* Muddy, fine to medium angular sand with common heavy mineral.
*Salinity:* Winter—less than 5 ‰. Summer—30-35 ‰.

B.—Lagoon proper

*Station 12*
*Sediment:* Poorly sorted angular quartz sand.
*Salinity:* Winter—less than 5 ‰. Summer—30-35 ‰.

*Station 2* (Location 60 of Imberger and Agnew).
*Sediment:* Clean angular quartz sand.
*Salinity:* Winter—less than 5 ‰. Summer—30-35 ‰.

#### *Channel samples*

*Station 1* Sand flat on edge of main channel.
*Sediment:* Admixture of dark grey mud coarse angular quartz sand and minor shell material.
*Salinity:* Winter—less than 5 ‰. Summer—35 ‰.

*Station 17* Main channel.
*Sediment:* Black mud with common faecal pellets, foraminifera, ostracods and sponge spicules.
*Salinity:* Winter—Surface—less than 5 ‰. Below halocline—5-30 ‰.

*Station 13* Edge of mobile sand bar (part of reverse delta).
*Sediment:* Well sorted calcareous sand.
*Salinity:* Winter—surface—less than 5 ‰, but sometimes varying with the tides. Summer—35 ‰ +

#### *Saline lakes*

The saline lakes—Swan Lakes and the Deadwater—are saline for a much longer part of the year than the rest of the Hardy Inlet system. As they are so shallow and as water access is only via very narrow channels, they have some features unique in the system. Although it is not properly documented, it is probable that they are slightly warmer than the waters in the rest of the study area. A figure of 4C° warmer than the water in Hardy Inlet itself has been mentioned (R. Lenanton, pers. comm.). Because of these factors a slightly hypersaline condition exists in part of the summer.

| STATION NUMBER | 9 | 10 | 8 | 7 | 6 | 5 | 4 | 3 | 11 | 12 | 2 | 1 | 17 | 13 | 15 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (km) from Inlet mouth | 8·5 | 7 | 8 | 6·5 | 4·5 | 4 | 4 | 3·5 | 7 | 5 | 3 | 2·5 | 2·5 | 0 | 2 | 1·5 | 1·5 | 1·5 |
| Setting | Tidal River | | | | Delta | | | | | Lagoon | | Channel | | | Lakes | | | Beach |
| Water Depth (m) | 7·5 | 1 | 1·2 | 1·5 | 1·5 | 1·5 | 0·7 | 1·2 | 1·2 | 1·2 | 0 | 1 | 5·5 | 1·2 | 0·5 | 0·3 | 1·5 | 0 |
| Number of specimens | 94 | 36 | 11 | 38 | 42 | 11 | 2 | 48 | 27 | 55 | 86 | 48 | 92 | 146 | 55 | 56 | 125 | 182 |
| Foraminiferal Number | 300 | 18 | 3 | 13 | 27 | 7 | 1 | 4 | 13 | 25 | 14 | 8 | 500 | 1200 | 1000 | 500 | 270 | 2500 |
| FISHER α INDEX / SPECIES | <1 | - | - | - | - | - | - | c.2 | - | c.2 | <2 | c.3 | 12 | 6 | <5 | c.10 | 11 | 10 |
| Protoschista findens | 1 | 7 | | 4 | | | | 1 | | 1 | 6 | | | | | | | |
| Ammonia beccarii | 89 | 6 | 10 | 4 | 1 | 3 | 1 | 10 | 6 | 5 | 3 | 38 | | | 15 | | | |
| A. tepida | 4 | | | | | | | | | | | | 4 | | 4 | | | |
| Ammobaculites agglutinans | | 7 | 1 | 18 | 8 | | | 3 | 18 | 18 | 22 | 4 | | | | | | |
| A. sp. 1 | | 16 | | | 33 | 6 | | 10 | 3 | 29 | 50 | | | | | | | |
| Bathysiphon sp 1 | | | | 1 | | | | | | | | | | | | | | |
| Psammosphaera sp. | | | | 11 | | 2 | 1 | 22 | | | 3 | | | | | | | |
| Miliammina fusca | | | | | | | | 1 | | | 2 | 1 | | | | | | |
| Trochammina inflata | | | | | | | | 1 | | 1 | | | | | | | | |
| ? Penardogromia sp | | | | | | | | | | 1 | | | | | | | | |
| ? Hyperammina sp | | | | | | | | | | | | 1 | | | | | | |
| Quinqueloculina simplex | | | | | | | | | | | | 1 | | | | | | |
| Elphidium crispum | | | | | | | | | | | | 3 | 3 | 37 | 1 | 9 | 16 | 29 |
| Triloculina inflata | | | | | | | | | | | | | 21 | | | 1 | 9 | |
| T. laevigata | | | | | | | | | | | | | 12 | | | 1 | 3 | |
| Quinqueloculina striata | | | | | | | | | | | | | 2 | | | | | |
| Q. lamarckiana | | | | | | | | | | | | | 3 | 4 | | 2 | 13 | 7 |
| Q. subpolygona | | | | | | | | | | | | | 2 | 2 | | | | |
| Spiroloculina angulata | | | | | | | | | | | | | 1 | | | | | |
| S. rotunda | | | | | | | | | | | | | 1 | | | | | |
| Miliolinella subrotunda | | | | | | | | | | | | | 5 | | | | | |
| ? Hauerina bradyi | | | | | | | | | | | | | 1 | | | | | |
| Fissurina fasc. carinata | | | | | | | | | | | | | 1 | | | | | |
| Oolina striatopunctata | | | | | | | | | | | | | 1 | | | | | |
| Bolivina sp. 1 | | | | | | | | | | | | | 2 | 1 | | | | |
| Buliminoides williamsonianus | | | | | | | | | | | | | 1 | | | | | |
| Reussella simplex | | | | | | | | | | | | | 1 | 2 | | 3 | 3 | 7 |
| Rosalina vilardeboana | | | | | | | | | | | | | 3 | | | | | |
| Neoconorbina terquemi | | | | | | | | | | | | | 1 | | | | | |
| Pileolina australensis | | | | | | | | | | | | | 4 | | | 1 | 4 | |
| P. patelliformis | | | | | | | | | | | | | 2 | | | 1 | 9 | 1 |
| Mississippina concentrica | | | | | | | | | | | | | 1 | | | | | |
| Spirillina inequalis | | | | | | | | | | | | | 1 | | | | | |
| Elphidium advenum | | | | | | | | | | | | | 2 | 2 | | 1 | | |
| E. poeyanum | | | | | | | | | | | | | 8 | | 22 | | 9 | |
| Cibicides refulgens | | | | | | | | | | | | | 1 | 19 | 2 | 6 | 17 | 22 |
| G. pseudoungerianus | | | | | | | | | | | | | 2 | | | | | |

Figure 4.—Foraminiferal distribution chart, Part 1.

| SPECIES \ STATION | 9 | 10 | 8 | 7 | 6 | 5 | 4 | 3 | 11 | 12 | 2 | 1 | 17 | 13 | 15 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planorb. mediterranensis | | | | | | | | | | | | | 1 | | | | | |
| Globigerina bulloides | | | | | | | | | | | | | 1 | | | | | |
| Turborotalia sp. | | | | | | | | | | | | | 2 | | | | | |
| Gaudryina convexa | | | | | | | | | | | | | | 3 | | | | 1 |
| Textularia pseudogramen | | | | | | | | | | | | | | 2 | | 1 | 2 | 4 |
| Marginopora vertebralis | | | | | | | | | | | | | | 4 | | | | 1 |
| Triloculina striatotrigonula | | | | | | | | | | | | | | 3 | | | | 1 |
| Discorbis australis | | | | | | | | | | | | | | 4 | | 1 | 1 | 4 |
| D. dimidiatus | | | | | | | | | | | | | | 40 | 1 | 16 | 15 | 67 |
| Gen. et sp indet 2 | | | | | | | | | | | | | | 1 | | | | |
| Elphidium jenseni | | | | | | | | | | | | | | 1 | | 2 | 3 | 2 |
| Valvulineria rugosa | | | | | | | | | | | | | | 1 | | | | |
| Acervulina inhaerens | | | | | | | | | | | | | | 11 | | 4 | | 7 |
| Gypsina globulus | | | | | | | | | | | | | | 7 | | | | 5 |
| ? Cassidulina sp | | | | | | | | | | | | | | 1 | | | | |
| Globigerina sp | | | | | | | | | | | | | | 1 | | | | |
| Rectobolivina raphanus | | | | | | | | | | | | | | | 1 | | | |
| Elphidium incertum | | | | | | | | | | | | | | | 3 | | | |
| E. simplex | | | | | | | | | | | | | | | 1 | | | 1 |
| Gypsina vesicularis | | | | | | | | | | | | | | | 1 | | | |
| Cymbaloporetta bradyi | | | | | | | | | | | | | | | 1 | | | |
| Q. seminulum | | | | | | | | | | | | | | | | 5 | | |
| Spiroloculina venusta | | | | | | | | | | | | | | | | 1 | 1 | |
| Hyperammina ? cylindrica | | | | | | | | | | | | | | | | 1 | | |
| Oolina sp | | | | | | | | | | | | | | | | | 1 | |
| Bolivinella australis | | | | | | | | | | | | | | | | | 2 | |
| Buliminella gracilis | | | | | | | | | | | | | | | | | 1 | |
| Bolivina striatula | | | | | | | | | | | | | | | | | 1 | |
| Heronallenia lingulata | | | | | | | | | | | | | | | | | 1 | |
| Planulinoides biconcavus | | | | | | | | | | | | | | | | | 3 | 2 |
| Pileolina opercularis | | | | | | | | | | | | | | | | | 4 | 3 |
| Spirillina decorata | | | | | | | | | | | | | | | | | 2 | 1 |
| Calcarina calcar | | | | | | | | | | | | | | | | | 2 | |
| Rotalia perlucida | | | | | | | | | | | | | | | | | 1 | |
| Dyocibicides biserialis | | | | | | | | | | | | | | | | | 1 | |
| Pyrgo lucernula | | | | | | | | | | | | | | | | | | 1 |
| Spiroloculina communis | | | | | | | | | | | | | | | | | | 2 |
| Triloculina trigonula | | | | | | | | | | | | | | | | | | 1 |
| Pavonina sp | | | | | | | | | | | | | | | | | | 1 |
| Rotalia trochidiformis | | | | | | | | | | | | | | | | | | 1 |
| Elphidium macellum | | | | | | | | | | | | | | | | | | 1 |
| Cellanthus craticulatus | | | | | | | | | | | | | | | | | | 4 |
| ? Crespinella sp | | | | | | | | | | | | | | | | | | 1 |
| Amphistegina lessonii | | | | | | | | | | | | | | | | | | 1 |

Figure 4.—Foraminiferal distribution chart, Part. 2.

A.—Swan Lakes

*Station 15*

*Sediment:* Pink, gelatinous, organic-calcium carbonate mud with superabundant ostracods. The sediment is almost an ostracod coquina. Study of this sample is hampered by difficulty in disaggregation due to high gelatinous organic content. Because of these difficulties the recorded relative abundance of various species may contain some error.

*Salinity:* Winter—low, less than 5 ‰. Summer—fully marine to a little hypersaline.

*Station 14* (Location 05.5 of Imberger and Agnew)—channel leading from Swan Lakes to the Deadwater. Sea grass covers channel floor.

*Sediment:* Carbonate sand.

*Salinity:* Winter—low, less than 5 ‰. Summer—fully marine to a little hypersaline.

B.—Deadwater

*Station 16* (Location 02 of Imberger and Agnew)—1.5-2 m —weed-covered lake floor.

*Sediment:* Poorly sorted carbonate sand showing much abrasion on the grains.

*Salinity:* Winter—(a) Low, less than 5 ‰ above 2 m. (b) Below 2 m, 10 ‰ or more. Summer—fully marine.

*Station 18*

*Sediment:* Approximately 90% carbonate sand. Well sorted.

### *Summer vs winter faunas*

The sediment at Station 9 was resampled on 23 February 1975, to see if there is any detectable difference between summer and winter faunas. If any difference is to be expected in the Hardy Inlet, Stations 7 to 10 would be expected to show it as they are in positions where summer-winter contrasts are greatest because the freshwater phase lasts longer than farther downstream.

Minor differences may be present. *Ammonia beccarii* is dominant in both summer and winter but *A. tepida* is apparently absent from summer faunas. Winter faunas may contain a higher foraminiferal number but more detailed, more closely spaced samples would be necessary to check this.

### *Effects of substrate on foraminifera*

The controlling feature on foraminiferal distribution in an estuarine system is mainly salinity but temperature and water depth also are important. Substrate influences generally are minor, but one species in Hardy Inlet is noteworthy for the relationship with substrate.

*Psammosphaera* sp. is common to dominant in some river and delta samples. Although it is not obvious in the figures (figures 6, 7) this species selectively isolates ilmenite for the construction of its agglutinated skeleton. The skeleton is not wholly of ilmenite but is very much enriched in it over the content in the sediment.

## Summary

The main features are summarised on Figure 3 but are discussed in more detail below.

*Tidal river biota:* The faunas contain low numbers of foraminifera and diversity also is low. It is notable that the more upstream samples (8, 10) contain the more dominant *Ammonia beccarii* faunas and the more downstream ones the more dominant agglutinated foraminifera, especially *Ammobaculites*. These faunas are the only ones in the entire study with abundant or common *A. beccarii*, with the exception of that from Station 1.

The other noteworthy feature in this regime is the flora which contains considerable numbers of charophytes (oogonia of characean algae) in three of the four samples. This is the only part of the area to contain noteworthy numbers of these organisms. Congdon has identified *Lamprothamnion* from this area during the course of the study.

*Delta biota:* As with the tidal river samples, foraminiferal numbers and diversities are low. The minor exception is at Station 3 where both are higher due to influence of the adjacent lagoon proper and of possible tidal marshes (dominantly the rush *Juncus maritimus*), both common habitats of *Miliammina fusca* and *Trochammina inflata*.

Faunas are dominantly of agglutinated foraminifera similar to the lower reaches of the tidal river but significantly different from those in upstream tidal river samples.

Charophytes are absent and ostracods are rare. Diversity of the biota in the delta is lower than in the tidal river. This probably reflects the area being the buffer between fluvial and marine regimes. Few species are versatile enough to survive these rapidly changing conditions.

*Lagoon proper:* The faunas of the two samples are virtually identical and show a marked increase in both diversity and foraminiferal number over the delta or tidal river faunas.

While extremes of summer and winter salinities are much the same as for most other samples, the vicinity of these stations has 8-9 months per year in which the salinity is higher than extreme winter values, a value between the longer freshwater phase upstream and shorter freshwater phase downstream ($1\frac{1}{2}$-2 months).

*Channel biota:* The foraminifera at Station 1 are akin to those in the lagoon with the exception that miliolids are present, suggesting that salinity reaches 32 ‰ or more for a considerable part of the year on the sand flats flanking the channel.

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Figures 5 to 34.—5.—?*Penardogromia* sp. Station 12, x 35 6, 7.—*Psammosphaera* sp. 6; Station 3, x 60; 7. Station 5, x 45. 8.—*Protoschista findens* (Parker), Station 2, x 30. 9.—*Miliammina fusca* (Brady), Station 2, x 55. 10.—*Ammobaculites agglutinans* (d'Orbigny), Station 2, x 60. 11.—*A.* sp. 1, Station 2, x 45. 12.—*Trochammina inflata* (Montagu), Station 3, x 95. 13.—*Textularia pseudogramen* Chapman and Parr, Station 13, x 45. 14.—*Gaudryina convexa* (Karrer), Station 13, x 55. 15.—*Triloculina inflata* d'Orbigny, Station 17, x 30. 16.—*T. laevigata* d'Orbigny, Station 17, x 80. 17.—*T. striatotrigonula* Parker and Jones, Station 13, x 50. 18.—*Quinqueloculina lamarckiana* d'Orbigny, Station 17, x 70. 19.—*Q. seminulum* (Linné), Station 14, x 75. 20.—*Q. striata* d'Orbigny, Station 17, x 90. 21.—*Q. subpolygona* Parr var., Station 17, x 80. 22.—*Miliolinella subrotunda* (Montagu), Station 17, x 90. 23.—*Spiroloculina communis* Cushman and Todd, Station 18, x 45. 24.—*S. venusta* Cushman and Todd, Station 14, x 60. 25.—*Marginopora vertebralis* Blainville, Station 13, x 60. 26.—*Bolivinella australis* Cushman, Station 16, x 65. 27.—*Bolivina* sp. 1, Station 13, x 65. 28.—*Reussella simplex* (Cushman), Station 13, x 45. 29, 30.—*Discorbis australis* Parr, Station 13, x 60; 29. dorsal; 30. ventral. 31, 32.—*D. dimidiatus* (Jones and Parker), Station 14, x 50.; 31. dorsail; 32. ventral. 33.—*Rosalina vilardeboana* d'Orbigny, Station 17, x 90. dorsal. 34.—*Planulinoides biconcavus* (Jones and Parker), Station 16, x 85.


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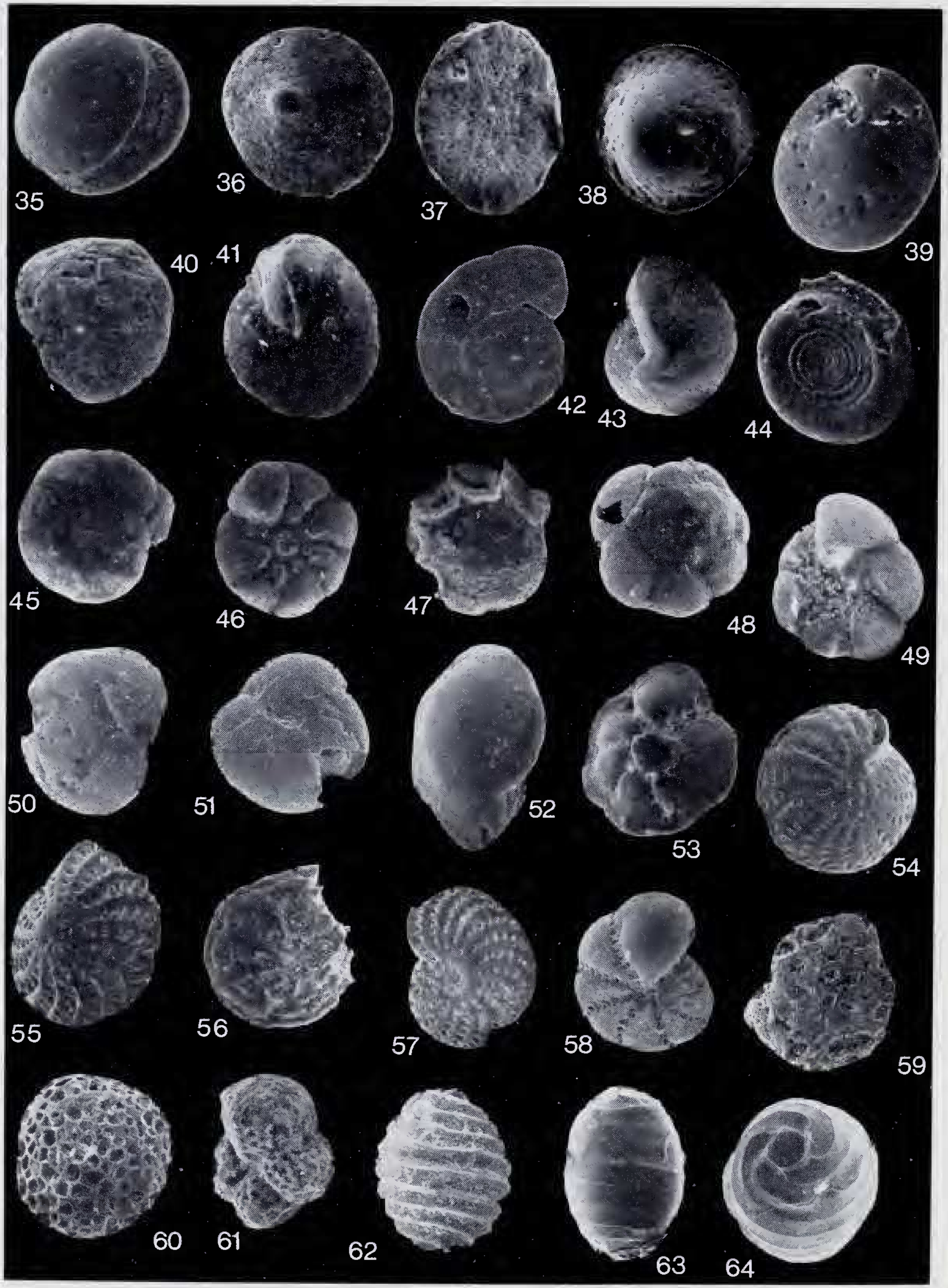

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The other two stations have typical marine faunas, that from station 17 probably approximately *in situ*, that from station 13 being virtually completely *"ex situ"*. Both faunas contain a few planktonic specimens. The simple arenaceous forms so typical of the upstream faunas are absent, miliolids are common to dominant and euryhaline species are virtually absent. There is no evidence of anything other than normal marine conditions in these samples.

*Saline lakes biota:* Samples 14 and 16 have faunas with high diversity and low dominance by a single species. This suggests a stable salinity/temperature regime, in contrast to Station 15 in Swan Lakes where two species are dominant. This latter seems a more specialised fauna reflecting a less stable salinity/temperature regime, probably because of a longer period per year of reduced salinity.

*Ocean beach fauna:* Three very similar foraminiferal faunas are those from Stations 13 (channel), 16 (Deadwater) and 18 (oceanic beach). Those from Stations 13 and 18 could be expected to be very similar as both are marine beach faunas in effect, with virtually none of the contained fauna *in situ*. The fact that the fauna at Station 16 is so similar would suggest that Locality 16 has marine conditions operating all year.

**List of species identified**

(Figure numbers in brackets after the species names refer to the accompanying illustrations).

Superfamily LAGYNACEA.
- *?Penardogromia* sp. (fig. 5).

Superfamily AMMODISCACEA.
- *Bathysiphon* sp. 1.
- *Hyperammina ?cylindrica* Parr, 1950. Rept. B.A.N.Z. *Antarctic Research Expedn*, 1929-31, Ser B, 5 (6): 254, pl. 3, fig. 5.
- *?Hyperammina* sp.
- *Psammosphaera* sp. (figs. 6, 7)—Like *P. fusca* but isolated from marine environment. *P. fusca* is deep water marine.

Superfamily LITUOLACEA.
- *Protoschista findens* (Parker) (fig. 8)=*Lituola findens* Parker, 1870. *Canad. Nat.* 5: 176 text figure 1.
- *Miliammina fusca* (Brady) (fig. 9)=*Quinqueloculina fusca* Brady, 1870. *Ann. Mag. Nat. Hist.* ser. 4, 6: 286, pl. 11 figs. 2, 3.
- *Ammobaculites agglutinans* (d'Orbigny) (fig. 10) =*Spirolina agglutinans* d'Orbigny, 1846. "Foraminiferes Fossils du Bassin Tertiaire de Vienne," 137, plfl 7, figs. 10-12.
- *Ammobaculites* sp. 1 (fig. 11).
- *Textularia pseudogramen* Chapman and Parr, 1937 (fig. 13). *Australas. Antarctic Expedn* 1911—14, *Sci. Rept.* Ser. C, 153.
- *Trochammina inflata* (Montagu) (fig. 12)= *Nautilus inflata* Montagu, 1808. "Testacea Brittanica . . .", Suppl. S. Woolmer, Exeter, 81, pl. 18, fig. 3.
- *Gaudryina convexa* (Karrer) (fig. 14)=*Textilaria convexa* Karrer, 1869. *"Novara" Expedn. Geol. Theil.* 1 (2): 78, pl. 16, figs. 8 a-c.

Superfamily MILIOLACEA.
- *Spiroloculina angulata* Cushman, 1917. *Bull. U.S. natn. Mus.* 71: 36, pl. 7, fig. 5.
- *Spiroloculina communis* Cushman and Todd, 1944 (fig. 23). *Spec. Publ. Cushman Lab. foramin. Res.* 11: 63 (figures, Brady, 1884. *"Challenger" Expedn. Scient. Results, Zool.* 9: pl. 9, figs. 5, 6).
- *Spiroloculina rotunda* d'Orbigny, 1826. *Annls. Sci. nat. ser.* 1, 7: 299.
- *Spiroloculina venusta* Cushman and Todd, 1944 (fig. 24). *Bull. U.S. natn. Mus.* 161: 39, pl. 9, figs. 11, 12.
- *Quinqueloculina lamarckiana* d'Orbigny, 1839 (fig. 18). "Histoire physique et naturalle de l'Ile de Cuba". 189 (figures 8: pl. 11, figs. 14. 15).
- *Quinqueloculina seminulum* (Linné) (fig. 19)= *Serpula seminulum* Linné. 1758. "Systema naturae" (10th edn) 1: 786.
- *Quinqueloculina simplex* Terquem, 1882. *Mem. Soc. geol. France,* ser. 3, 2 (3): 172, pl. 18, figs. 5-13.
- *Quinqueloculina striata* d'Orbigny, 1843 (fig. 20)= *Q. striata* d'Orbigny, 1826. *Annls Sci. Nat.* ser. 1, 7: 301.
- *Quinqueloculina subpolygona* Parr, 1945 (fig. 21). *Proc. R. Soc. Vict.* 56 (2): 196, pl. 12, figs. 2 a-c.
- *Triloculina inflata* d'Orbigny, 1826 (fig. 15). *Annls Sci. nat.* ser. 1, 7: 300.
- *Triloculina laevigata* d'Orbigny, 1378 (fig. 16). *Annls Sci. nat.* ser. 1, 7: 134.
- *Triloculina striatotrigonula* Parker and Jones, 1865 (fig. 17). *Phil. Trans. R. Soc.* 155: 438.
- *Miliolinella subrotunda* (Montagu) (fig. 22)= *Vermiculum subrotundum* Montagu, 1803. "Testacea Brittanica . . . ", 521.
- *Hauerina bradyi* Cushman, 1917. *Bull. U.S. nat. Mus.* 71: 62, pl. 23, fig. 2.
- *Marginopora vertebralis* Blainville, 1830 (fig. 25). "Dictionnaire des Sciences Naturelles". Levrault, Paris. v. 60, 377, (figures Blainville, 1834, "Manuel d'Actinologie", pl. 69, fig. 6).

Superfamily NODOSARIACEA
- *Bolivinella australis* Cushman, 1929 (fig. 26). *Contr. Cushman Lab. foramin. Res.* 5 (2): 32, pl. 5, figs. 6, 7.
- *Oolina melo* d'Orbigny, 1839. "Voyage dans l'Amerique Meridionale; Foraminiferes". Levrault, Strasbourg. 5 (5) · 20, pl. 5, fig. 9.
- *Fissurina fasciata carinata* (Sidebottom), 1906. *Mem. Proc. Lit. Phil. Soc. Manchester,* 7, pl. 1, fig. 17.

Superfamily BULIMINACEA
- *Buliminoides williamsonianus* (Brady)=*Bulimina williamsoniana* Brady, 1881. *Quart. Jour. microsc. Soc.* 21: 56.
- *Buliminella gracilis* Collins, 1953. *Mem. Nat. Mus. Melbourne,* 18: 102, pl. 1, figs. 8 a, b.
- *Bolivina striatula* Cushman, 1922. *Publ. Carnegie Instn. Washington,* 311, 27, pl. 3, fig. 10.
- *Bolivina* sp. 1 (fig. 27).
- *Rectobolivina raphanus* (Parker and Jones)= *Uvigerina (Sagrina) raphanus* Parker and Jones, 1865. *Phil Trans. R. Soc.* 155: 364, pl. 18, figs. 16, 17.
- *Reussella simplex* (Cushman), 1929 (fig. 28)= *Trimosina simplex* Cushman, 1929. *Jour. Washington Acad. Sci.* 19: 158.

Superfamily DISCORBACEA
- *Discorbis australis* Parr, 1932 (figs. 29, 30). *Proc. R. Soc. Vict.,* 44 (2): 227, pl. 22, fig. 31.
- *Discorbis dimidiatus* (Jones and Parker) (figs. 31, 32)=*Discorbina dimidiata* Jones and Parker, 1862, *in* Carpenter "Introduction to the study of the foraminifera", *Ray Soc. Publns. London,* 201, text fig. 32B.
- *Planulinoides biconcavus* (Jones and Parker) (fig. 34)=*Discorbina biconcava* Jones and Parker, 1862. *Ray Soc. Publns* (1862): 201, tab .32g.

Figures 35 to 64.—35.—*Pileolina australensis* (Heron-Allen and Earland), Station 16, x 100. Oblique view of plastogamic pair. 36, 37.—*P. opercularis* (d'Orbigny), Station 16, x 100; 36. dorsal; 37. ventral. 38, 39.—*P. patelliformis* (Brady), Station 16, x 100; 38. dorsal; 39. ventral. 40, 41.—*Cibicides pseudoungerianus* (Cushman), Station 17, x 100.; 40. dorsal; 41. ventral. 42, 43.—*C. refulgens* Montfort, Station 14, x 70; 42. dorsal; 43. ventral. 44.—*Spirillina decorata* Brady, Station 16, x 125. 45, 46.—*Ammonia beccarii* (Linné), Station 1, x 95; 45. dorsal; 46. Ventral. 47.—*A. beccarii*, Station 7, x 70. Note effects of dissolution. 48, 49.—*A. tepida* (Cushman), Station 17, x 125; 48. dorsal; 49. ventral. 50, 51.—*Rotalia perlucida* Heron-Allen and Earland, Station 13, x 60; 50. dorsal; 51. ventral. 52, 53.—*Calcarina calcar* d'Orbigny, Station 16, x 120; 52. dorsal; 53. ventral. 54.—*Elphidium advenum* (Cushman), Station 13, x 50. 55.—*E. crispum* (Linné), Station 13, x c.70 56.—*E. incertum* (Williamson), Station 15, x c.100. 57.—*E. jenseni* (Cushman), Station 13, x 50. 58.—*E. poeyanum* (d'Orbigny), Station 17, x 65. 59.—*Acervulina inhaerens* Schultze, Station 13, x 55. 60.—*Gypsina globulus* (Reuss), Station 13, x 65. 61.—*Globorotalia* sp., Station 17, x 125. 62-64.—Charophytes, Station 8; 62, x 50; 63, 64, different form, x 60.

*Rosalina (Neoconorbina) terquemi* (Rzehak)= *Discorbina terquemi* Rzehak, 1888. *Verh. K.K. geol. Reichensanst. Wien* (1888): 228.

*Rosalina vilardeboana* d'Orbigny, 1839 (fig. 33). "Voyage dans l'Amerique Meridionale; Foraminiferes", Levrault, Strasbourg, 5 (5), 44, pl. 6, figs. 13-15.

*Heronallenia lingulata* (Burrows and Holland)= *Discorbina lingulata* Burrows and Holland, 1895. *Monogr. Palaeontogr. Soc.* (1895), pl. 7, figs. 33 a-c.

*Pileolina australensis* (Heron-Allen and Earland) (fig. 35)—*Discorbina pileolus* (d'Orbigny) (See Brady, 1884, *"Challenger" Expedn. Scient. Results, Zool.* 9: 649, pl. 89, figs. 2-4).

*Pileolina opercularis* (d'Orbigny) (figs. 36, 37)= *Discorbina opercularis* d'Orbigny (see Brady, 1884. *"Challenger" Expedn. Scient. Results, Zool.* 9: 650, pl. 89, figs. 8, 9.

*Pileolina patelliformis* (Brady), 1884 (figs. 38, 39)= *Discorbina patelliformis* Brady, 1884. *"Challenger" Expedn. Sci. Results, Zool.*, 9: 647, pl. 89, figs. 1 a-c.

*Pileolina tabernacularis* (Brady), 1881.=*Discorbina tabernacularis* Brady 1881. *Quart. Jour. microsc. Soc.* n.s. 21: 65 (Figures Brady, 1884—*"Challenger" Expedn. Scient. Results, Zool.* 9: pl. 89, figs. 5-7).

*Valvulineria rugosa* (d'Orbigny), 1839=*Rosalina rugosa* d'Orbigny, 1839. "Voyage dans l'Amerique meridionale; Foraminiferes", Levrault, Strasbourg, 5 (5): 42, pl. 2, figs. 12-14.

*Mississippina concentrica* (Parker and Jones)= *Pulvinulina concentrica* Parker and Jones, 1864. *Trans. Linn. Soc.* 24: 470, pl. 48, fig. 14.

*Amphistegina lessonii* d'Orbigny, 1826. *Annls. Sci. Nat.*, ser. 1, 7: 304, pl. 17, figs. 1-4.

*Cibicides pseudoungerianus* (Cushman), 1922 (figs. 40, 41)=*Truncatulina pseudoungeriana* Cushman, 1922. *Prof. Pap. U.S. geol. Surv.* 129E, 97, pl. 20, fig. 9.

*Cibicides refulgens* Montfort, 1808 (figs. 42, 43). *Conch. System.* 1: 122.

*Dyocibicides biserialis* Cushman and Valentine, 1930. *Contr. Dept. Geol. Stanford Univ.* 1 (1): 31, pl. 10, figs. 1, 2.

*Planorbulina mediterranensis* d'Orbigny, 1826. *Annls. Sci. nat. scr.* 1, 7: 280, pl. 14, figs. 4-6.

*Acervulina inhaerens* Schultze, 1854 (fig. 59). Über der Organismus der Polythalamion (Foraminiferen) nebst Bemerkungen über die Rhizopoden im allgemeinen". Leipzig; Engelmann, 68, pl. 6, fig. 12.

Superfamily SPIRILLINACEA

*Spirillina decorata* Brady, 1884 (fig. 44). *"Challenger" Expedn. Scient. Results, Zool.* 9: 633, pl. 85, figs. 22-25.

*Spirillina inequalis* Brady, 1879. *Quart. J. microsc. Soc.* 19: 278, pl. 8, fig. 25.

Superfamily ROTALIACEA

*Ammonia beccarii* (Linné) (figs. 45, 46, 47)= *Nautilus beccarii*, 1767. "Systema naturae" 12th edn., 1162.

*Ammonia tepida* (Cushman) (figs. 48, 49)= *Rotalia beccarii* var. *tepida* Cushman, 1926. *Carnegie Inst. Washington Publ.* 344: 79, pl. 1.

*Rotalia perlucida* Heron-Allen and Earland, 1913 (figs. 50, 51). *Proc. R. Irish Acad.* 31 (64): 139, pl. 13, figs. 7-9.

*Calcarina calcar* d'Orbigny, 1826 (figs 52, 53). *Annls. Sci. nat.* ser. 1, 7: 276, modeles No. 34.

*Elphidium advenum* (Cushman) (fig. 54)=*Polystomella advena* Cushman, 1922. *Carnegie Inst. Washington, Publn.* 311, 56, pl. 9, figs. 11, 12.

*Elphidium crispum* (Linnė) (fig. 55)=*Nautilus crispus* Linnė, 1758, "Systema naturae", 10th Edn. 709.

*Elphidium incertum* (Williamson), 1858 (fig. 56)= *Polystomella umbilicatula* var. *incerta* Williamson, 1858. "On the Recent foraminifera of Great Britain". *Ray Soc. London*, 44, pl. 3, fig. 82a.

*Elphidium jenseni* (Cushman) (fig. 57)=*Polystomella jenseni* Cushman, 1924. *Carnegie Inst. Washington, Publn.* 342: 49, pl. 16, figs. 4, 6.

*Elphidium poeyanum* (d'Orbigny) (fig. 58)= *Polystomella poeyana* d'Orbigny, 1839. "Histoire physique, politique et naturelle de l'ile de Cuba". 55, pl. 14, fig. 26.

*Elphidium simplex* Cushman, 1933. *Bull. U.S. nat. Mus.* 161 (2): 52, pl. 12, figs. 8, 9.

*Gypsina globulus* (Reuss) (fig. 60)=*Ceriopora globulus* Reuss, 1848. *Naturw. Abh., Berlin* 2 (2): 33.

*Gypsina vesicularis* (Parker and Jones), 1860= *Orbitolina vesicularis* Parker and Jones 1862. *Ann. Mag. Nat. Hist.* ser. 3, 6: 31, no. 5.

*Cymbaloporetta bradyi* Cushman, 1915. *Bull. U.S. nat. Mus.* 71 (6): 25, pl. 10, figs. 2 a-c; pl. 14, figs. 2 a-c.

Superfamily CASSIDULINACEA

?*Cassidulina* sp.

Superfamily GLOBIGERINACEA

*Globigerina bulloides* d'Orbigny, 1826. *Annls. Sci. nat.* ser. 1, 7: 277, Modeles No. 17.

*Globorotalia* sp. (fig. 61).

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## References

Albani, A., (1968).—Recent Foraminiferida of the central coast of New South Wales. *Aust. Marine Sci. Assoc. Handbook*, 1: 1-37.

Apthorpe, M., (1974).—Distribution of recent foraminifera (Protista) in the Gippsland Lakes, Victoria, Australia. *Aust. Marine Sci. Assoc. Bull.* 47, 6.

Bandy, O. L., Ingle, J. C., and Resig, J. M., (1964).—Foraminifera, Los Angeles County outfall area, Californa. *Limnol. Oceanogr.* 9: 112-123.

Betjeman, K. J., (1969).—Recent foraminifera from the western continental shelf of Western Australia. *Contr. Cushman Fdn Foram. Research.* 20 (4), 119-139, pl. 18, 19.

Cushman, J. A., (1948).—"Foraminifera: their classification and economic use" Harvard University Press: Cambridge, Mass. 605 pp., 55 pls.

Cushman, J. A. and Todd, R., (1944).—The genus *Spiroloculina* and its species. *Bull. U.S. natn. Mus.* 161 (1).

Glaessner, M. F., (1945).—"Principles of micropalaeontology" Melbourne Univ. Press: Melbourne, 296 pp.

Imberger, J., and Agnew, H. (in press).—Gravitational currents in the Blackwood River Estuary. *Proc. Fifth Australas. Conf. Hydraulics and Fluid Mech.*, Christchurch, 1974.

Loeblich, A. R. and Tapan Helen (1964).—"Treatise on Invertebrate Paleontology", Part C, Protista 2, vols. 1, 2. 900 pp. (Geol. Soc. Amer. and Univ. of Kansas Press: Lawrence, Kansas).

McKenzie, K. G. (1962).—A record of foraminifera from Oyster Harbour near Albany, Western Australia. *J. R. Soc. West. Aust.* 45 (4): 117-132, pl. 1-3.

Murray, J. W. (1973).—"Distribution and ecology of living benthic foraminiferids". Heinemann Educational Books: London etc., 274 p. 103 figs., 12 pls.

Phleger, F., (1951).—Ecology of foraminifera, northwest Gulf of Mexico, Part 1, Foraminifera distribution. *Mem. geol. Soc. Am.* 46: 1-88.

Phleger, F., (1955).—Ecology of foraminifera in the south-eastern Mississippi Delta area. *Am. Assoc. Petrol. Geol. Bull.* 39: 712-752.

Phleger, F., (1960).—"Ecology and distribution of Recent foraminifera", Johns Hopkins Press: Baltimore, 297 pp.

Schafer, C. T., (1970).—Studies of benthonic Foraminifera in Restigouche Estuary: I Faunal distribution patterns near pollution sources. *Maritime Sediments*, 6: 121-134.

Seiglie, G. A., (1970).—The distribution of the foraminifera in Yabucoa Bay, southeastern Puerto Rico and its paleoecological significance. *Revista Espan. Micropaleont.* 2: 183-208.

Walton, W. R., (1964).—Recent foraminiferal ecology and paleoecology, *in* Imbrie, J. and Newell, N., 1964—"Approaches to paleoecology" (John Wiley and Sons: New York), 151-237.